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Research Note

An Electromechanical Method of Scanning the Stretch Array

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ELECTROMAGNETIC RADIATION LABORATORY PROJECT 4642

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Abstract

A new type of antenna array consists of dipole elements, proximity coupled to a two-wire transmission line. Scanning is accomplished by changing the spacing between elements. A method of scanning using electromechanical methods is described which is particularly useful in large antenna systems over the frequency range of about 50 Mcps to 500 Mcps.

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An Electromechanical Method of Scanning the Stretch Array

1. INTRODUCTION

A new type of antenna array consists of dipole elements, proximity coupled to a two-wire transmission line. The dipoles are supported at a fixed height above the transmission line and the spacing between dipoles is varied from $\lambda/2$ to λ. To properly scan this antenna the elements must be moved according to

$$\Delta Xq = q \Delta X_1 \tag{1}$$

where ΔXq is the distance moved by the q<u>th</u> element and ΔX_1 is the distance moved by the first element. A method of scanning that satisfies Eq. (1) may be easily obtained if ΔX_1, instead of being continuous, is limited to discrete values. For example, $\Delta X_1 = \lambda/50$ would be suitable. If it is desired to change the element spacing by more than $\lambda/50$, then Eq. (1) can be satisfied by moving the elements such that $\Delta Xq_{\text{total}} = nq\Delta X_1$ where $n = 1, 2, 3, \ldots 25$ is the number of increments that the first element moves.

Each element is mounted on its own motor-driven carriage along with a small stepping switch. These carriages move along a rail on which are located index points at intervals of $\lambda/50$. Each time the carriage passes over an index point the stepping switch on the carriage is advanced by one count. Each carriage is identical except that the stepping switch is adjusted to remove the power from the drive

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motor at a different count. In this way the first carriage is made to move $\lambda/50$, the second $\lambda/25$, and so forth. By repeating the above process the element spacing may be adjusted to any integral number of increments between $\lambda/2$ and λ.

Antenna scanning is accomplished through a control panel and is completely automatic. The operator need only select the desired element spacing on the control panel. The antenna then moves in the proper direction until the correct spacing is obtained, stops, and lights a lamp on the control panel to show that the scan has been completed. The antenna may also be calibrated. When a calibrate switch is depressed all elements move to their full contracted positions and all stepping switches are returned to zero. Again a lamp is lighted to show that calibration has been completed. Provision has also been made for scanning the antenna in the "manual mode". In this mode the spacing is changed by only one increment regardless of the setting of the spacing selector switches. Other features include interlocks that prevent scan complete and calibration complete indications until all elements are in their proper positions.

2. SYSTEM DESCRIPTION

2.1 Normal Scan

During the normal scan mode of operation (either forward or reverse), closing the scan switch unlocks the start scan, calibration complete, and the calibration start relays, (Fig. 1). At the same time the reset time-delay and the step-coil time-delay relays are energized. The reset time-delay relay removes power from the motors and energizes the reset line causing all carriage stepping switches to go back to zero (Fig. 2). Simultaneously the step-coil time-delay relay removes power from the step coils and the relays on the carriages. This allows the interlock line to open and the motor common line to close at each carriage. Three seconds after closure the reset time delay drops out, removing power from the reset line and closing the motor common line, thus allowing the carriages to start moving. Two seconds later the step-coil time-delay relay drops out applying power to the step-coil line and the relay-control line. The delay between drop out of the reset time-delay relay and step-coil time-delay relay is necessary to prevent false counts at a carriage if it has stopped on an index point thus keeping S_1 closed.

Each time a carriage moves over an index point S_1 closes, advancing the stepping switch by one count. After the proper number of counts (one for the first carriage, two for the second, and so forth), S_2, which is mounted on and activated by the stepping switch, closes causing the carriage relay to pull in and lock. This closes the interlock line and removes power from the motor for this

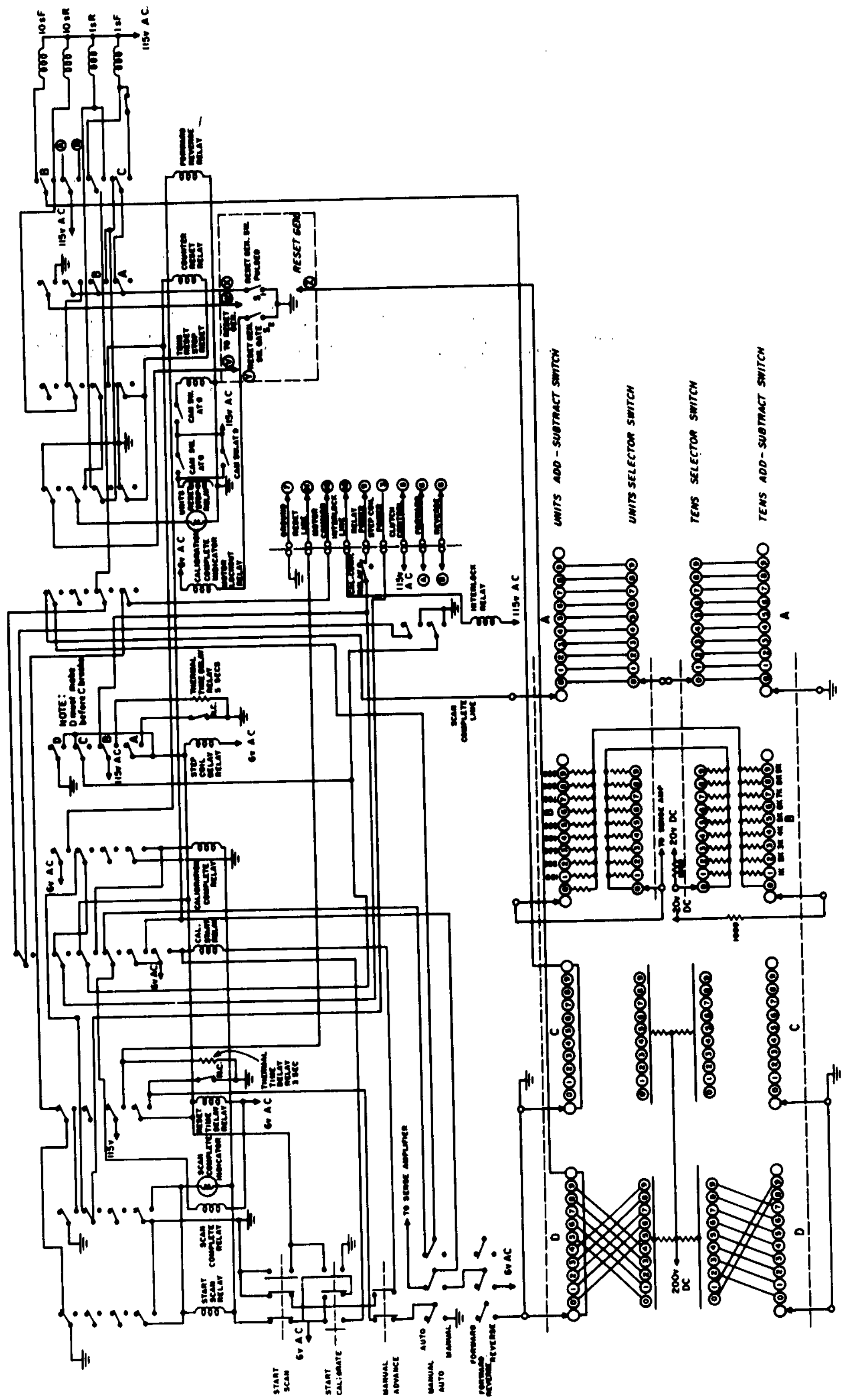

Figure 1. Control panel wiring diagram

carriage. When all carriages have stopped moving, the interlock relay is energized through the ground provided by the interlock line. Closure of the interlock relay advances (either forward or reverse depending on the state of the forward-reverse relay) the units add - subtract stepping switch by one count and simulates closure of the start-scan switch causing a new scan cycle to begin.

Inspection of the add - subtract switch connections in Fig. 1 shows that if the element spacing selector switch and the add - subtract stepping switch are at the same position, the scan complete line is returned to ground. After the proper number of scans, equal to the difference between the indicated element spacing and the spacing selected by the element spacing selector switch, the scan-complete line energizes the scan-complete relay causing the scan-start relay to also pull in. This removes power from the motors and the step-coil line and lights the scan-complete indicator. Grounding of the scan-complete line is simultaneous with the closure of the interlock relay so that five seconds later all power is removed from the carriages and they will remain in this position until a new command is given to the control panel.

2.2 Calibration Mode

If for some reason the carriages should not be in their correct positions, depressing the calibration-start switch will cause them to move until the element spacing is $\lambda/2$. Closure of this switch causes the start-scan relay to drop out and energizes the calibration-start relay, the reset time-delay relay, and the step-coil time-delay relay. System operation in this mode is the same as previously described for normal scan with the following exceptions: Since the calibration-start relay energizes the forward-reverse relay, the carriages always move in the reverse direction. The calibrate-start relay never allows the step-coil power line to be energized, thus preventing the carriage stepping switches from counting. This relay also transfers the interlock line from the scan-complete to the calibration-complete relay. The carriages therefore move continuously until they arrive at an auxiliary index point on the rail where S_3 closes causing the carriage relay to pull in and lock. When all carriages have arrived at their auxiliary index points (spaced $\lambda/2$ apart) the interlock relay is energized causing the reset-time delay, the step-coil time delay, and the calibration-complete relays to pull in. The carriage stepping switches are reset as described while the calibration-complete relay activates the reset generator which returns the add-subtract relays to zero. During the calibration mode the scan-complete line is disabled by the calibration-start relay. Again all power is removed from the carriages causing them to remain in this position until reception of another command by the control panel.

2.3 Manual Mode

When the manual-auto switch is in the manual position the carriages move by

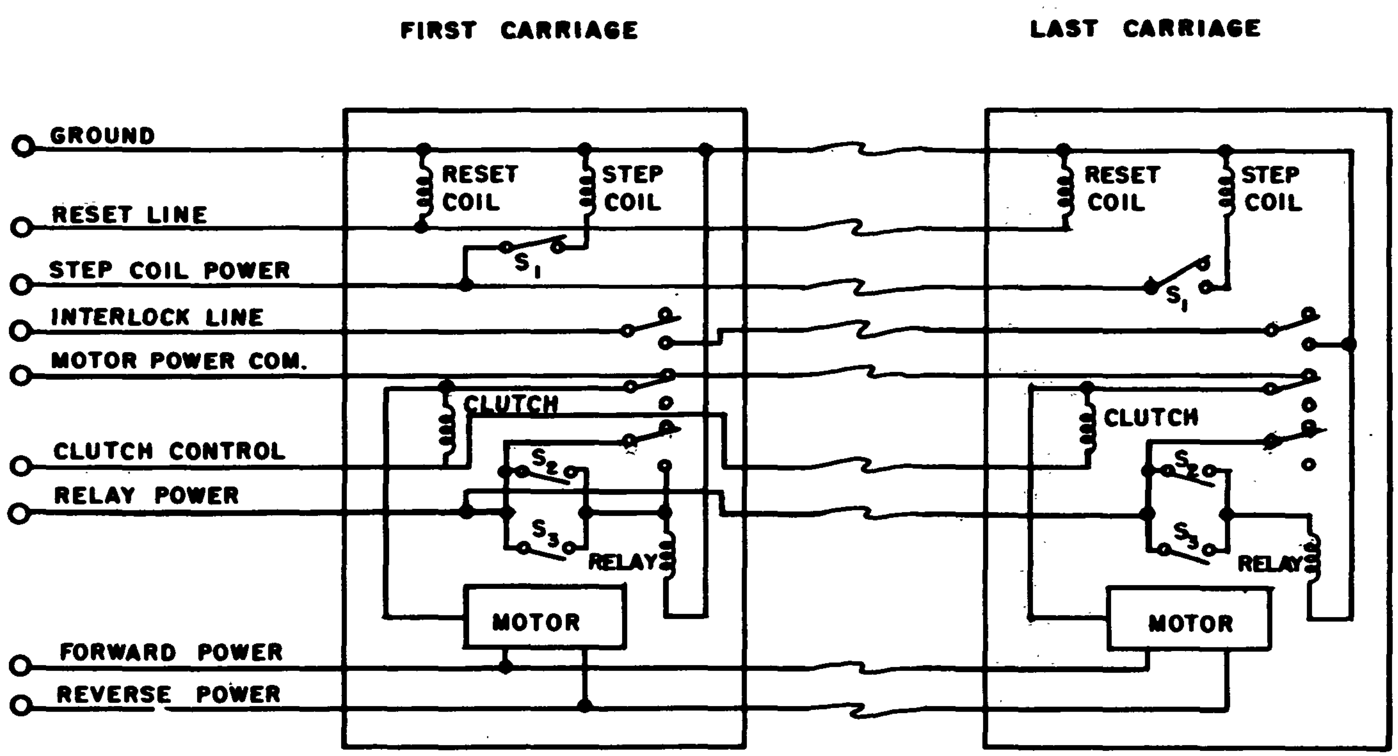

Figure 2. Carriage wiring diagram

only one scan cycle and stop, regardless of the position of the element-spacing selector switch, whenever the manual advance switch is depressed. Inspection of Fig. 1 shows that when the manual-auto switch is in the manual position, the scan complete line is opened, the forward-reverse relay is energized through the forward-reverse switch, and the reset-time delay relay and step-coil delay relay once pulled in remain locked. Therefore, depressing the manual advance switch initiates a normal-scan cycle (either forward or reverse depending on the position of the forward-reverse switch). Upon completion of the cycle the interlock relay is activated causing the reset time-delay relay and the step-coil time-delay relay to pull in and lock. Since the auto-manual switch shorts out the contacts of the thermal time-delay relay to ground, the delay relays cannot drop out thus preventing further movement of the carriages. Simultaneously the units add-subtract relay is advanced one count in the proper direction.

2.4 Indicators

One pole of each of the add-subtract relays is connected to a NIXIE indicator, thus showing the element spacing of the array at all times. Another pole of each add - subtract stepper is connected to another set of NIXIES showing the angle that the antenna beam makes with broadside. A third pole on each stepping switch is used for providing a signal for the sense amplifier, while a fourth pole is used for the scan-complete line.

2.5 Reset Generator

Figure 3 shows the schematic for the reset generator needed in the calibration mode and whenever two digits in the indicated element spacing must be changed, for example, in going from nine to ten or nineteen to twenty, and so forth. The generator produces a series of relay closures thus advancing the add-subtract relays to their proper positions. For example, when the calibration-complete relay is energized at the end of a calibrate cycle it pulls in the counter-reset relay thus activating the reset generator and causing C_1 in the generator to open and close at a 2-cps rate. Since in the calibrate mode the forward-reverse relay is energized, the reset pulses go through the units and tens reset-stop relays to the units and tens reverse-coil stepping relays. When the steppers reach zero position, cam switches are closed energizing the reset-stop relays that disconnect the reset-generator line from the stepping switches. The counter-reset relay coil is returned to ground through the units and tens reset-stop relay contacts wired in parallel. In this way, only after both stepping switches have returned to zero is the reset relay released, stopping the reset generator. The two reset-stop relays also provide power for the calibration complete indicator. Two sets of relay contacts, connected in series, prevent the lamp from lighting until both stepping switches are back to zero. The last two features described are necessary since,

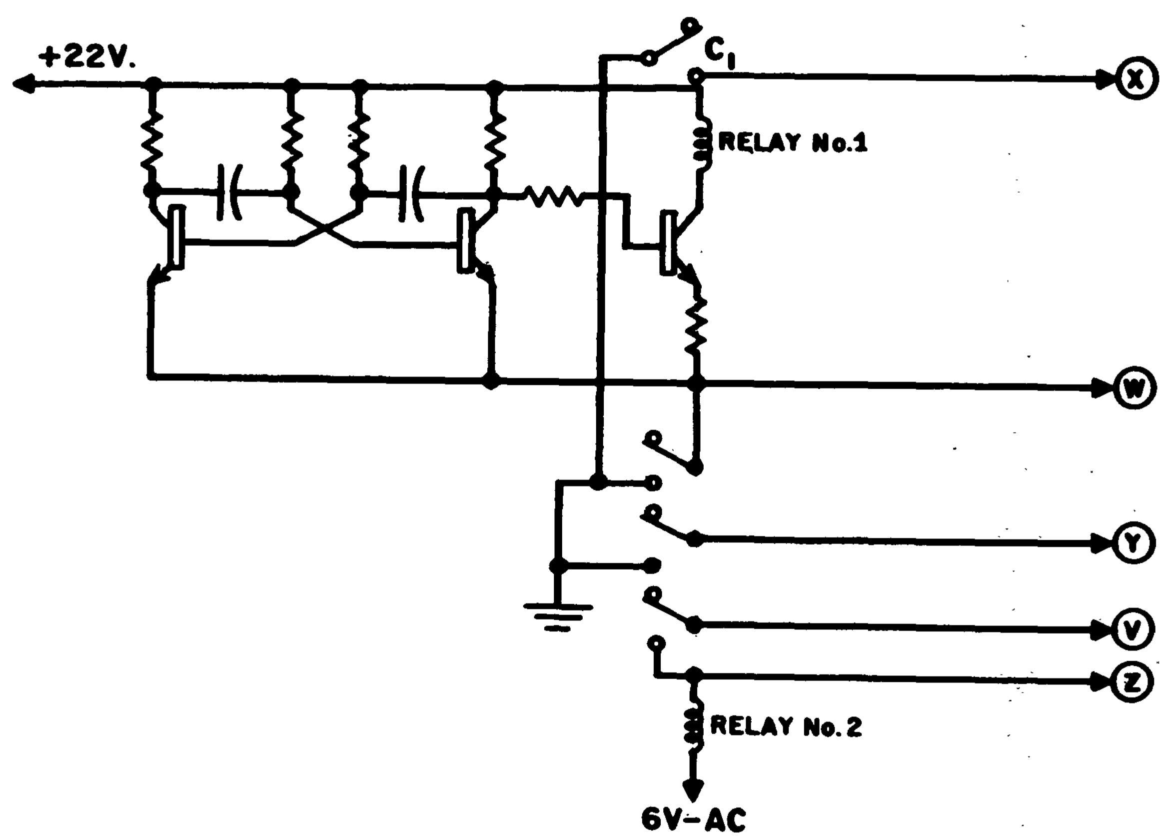

Figure 3. Reset generator

generally, when calibration is initiated the indicated count is not made up of two equal digits. For example, a count of seventeen requires the tens stepper to advance once while the units stepper must advance seven counts.

The reset generator is also used when scanning whenever two digits in the indicated count must be changed. Inspection of Fig. 1 shows that although only ten contacts are used on each pole of the add-subtract steppers, poles C and D of the units stepping switch have twelve positions, one extra at each end. These extra poles are used in the following way. Assume that the indicated count is nine and the antenna is scanning towards fifteen. At the completion of a scan cycle the units stepper would be advanced from position nine to one of the extra positions. Pole C of the units stepper provides a momentary ground for the tens stepper forward coil, advancing it from zero to one. Simultaneously, pole D activates the reset generator and the motor-lockout relay (needed to prevent the carriages from moving or a scan complete indication while the steppers are moving to their proper positions) through Relay 2. The reset pulses are applied to the units-reverse stepper through the units-reset stop relay. When the units stepper reaches zero, the units-reset stop relay is energized stopping the units stepper and the reset generator. This causes the motor lockout relay to drop out applying power to the motors. The count is now ten and the antenna continues scanning towards fifteen. When scanning in the reverse direction the forward-reverse relay is energized causing pole C to step the units-reverse stepper to subtract one count and the units-forward stepper to add nine counts. The rest of the sequence is identical with operation in the forward direction.

Figure 3 shows that the reset generator is simply an astable multivibrator driving a relay (Relay 1), the multi being controlled by Relay 2. During calibration, reset line W is continuously grounded by the counter reset relay thus activating the generator. Contacts C_1 on Relay 1 open and close at a 2-cps rate resetting the add-subtract steppers. When both steppers reach zero W is opened and the reset generator stops.

When scanning, the generator "sees" a momentary ground on Z which causes Relay 2 to pull in and lock through V which goes to ground through the units reset stop relay. This activates the generator and pulls in the motor lockout relay. When the steppers reach their proper positions, the units reset stop relay pulls in allowing Relay 2 to drop out, stopping the reset generator and releasing the motor lockout relay.

2.6 Sense Amplifier

The sense amplifier is used to automatically determine whether the antenna should extend or contract to make the indicated element spacing equal to the selected element spacing. Poles B of the units and tens add-subtract switches and

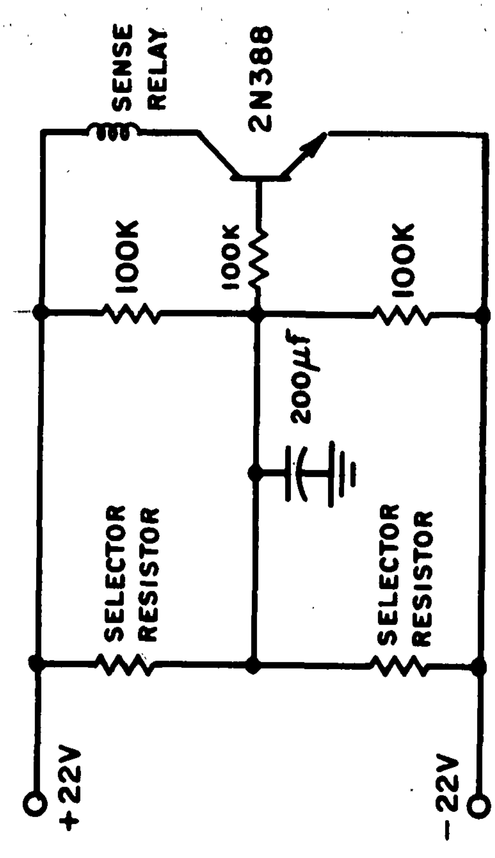

Figure 4. Sense amplifier

the units and tens selector switches are connected through resistors so that they form a balanced voltage divider. If the selected and indicated spacing are the same the voltage at the junction of the divider is zero. If the indicated spacing is larger than the selected spacing the junction of the divider is positive. The positive voltage causes the zero-biased transistor to conduct energizing the sense relay (Fig. 4). The contacts on the sense relay energize the forward-reverse relay allowing the array to contract towards the selected spacing. If the junction voltage is negative, the transistor is driven further into cufoff thus keeping the sense relay from pulling-in making the array extend when scanning.

2.7 Construction

The rail on which the carriages move is a standard aluminum I beam $2\frac{1}{2}$ in. wide.. The Extuchion nails are driven into holes drilled in the rail at proper intervals (Figs. 5, 6, and 7). The carriages are made of a section of channel about 8 in. long. One pair of wheels is driven by a 60-rpm synchronous motor through two spur gears. Because standard components are used, very little machining is required to assemble the antenna and thus the cost is kept low.

The short mast supporting the elements extends up above the carriages through a slot in the ground plane mounted above the rail. In this way the carriages do not affect the electrical characteristics of the antenna (Fig. 8).

3. DISCUSSION

This electro-mechanical scheme of scanning has several advantages besides simplicity of operation. The accuracy obtainable is extremely good and only dependent on the spacing of the index points on the rail. Accuracies of 1/4 in. per 1000 ft can be easily obtained. The system once set up requires little or no maintenance and is not affected by extremes of temperature. Relays being inherently reliable, give the system high reliability. The system is very flexible because the control panel can be used to control any number of elements without modification. The cost of the system is quite modest.

In designing the original model no real attempt was made to simplify circuitry, and so forth, as much as possible. Several refinements are however obvious. On the carriages switches S_1 and S_2, which are now microswitches, could be replaced by wipers that touch the rail at every index point. If the rail were grounded these wipers would completely replace the microswitches at a considerable saving . If the contacts of the carriage stepping switch were used, microswitch S_2 could be eliminated. By using an extra pole on the carriage relay and switching the motor power through the forward and reverse lines instead of the common, at least one wire could be eliminated from the intercarriage cable. Several other

improvements in component efficiency and system operation are also possible.

Usefulness of this scanning method is limited to large arrays (thirty or more elements) at frequencies below 400 Mcps. For smaller arrays other methods offer distinct advantages.

For large arrays with many elements beamwidths become very small and more index points should be added to allow changes of spacing smaller than $\lambda/50$. At 100 Mcps $\lambda/200$ would probably be a lower limit to the size of the increments. It is possible, however, to perturb the motion of the carriages to give still smaller effective increments. For example, only a portion of the elements could be moved until spacing errors build up to a certain nonacceptable limit. At this point the rest of the elements would be moved to correct the errors. In this way very small effective increments could be obtained while maintaining reasonable spacing of the index points. This carriage motion could be easily controlled by a program wired into the control-panel add-subtract relays.

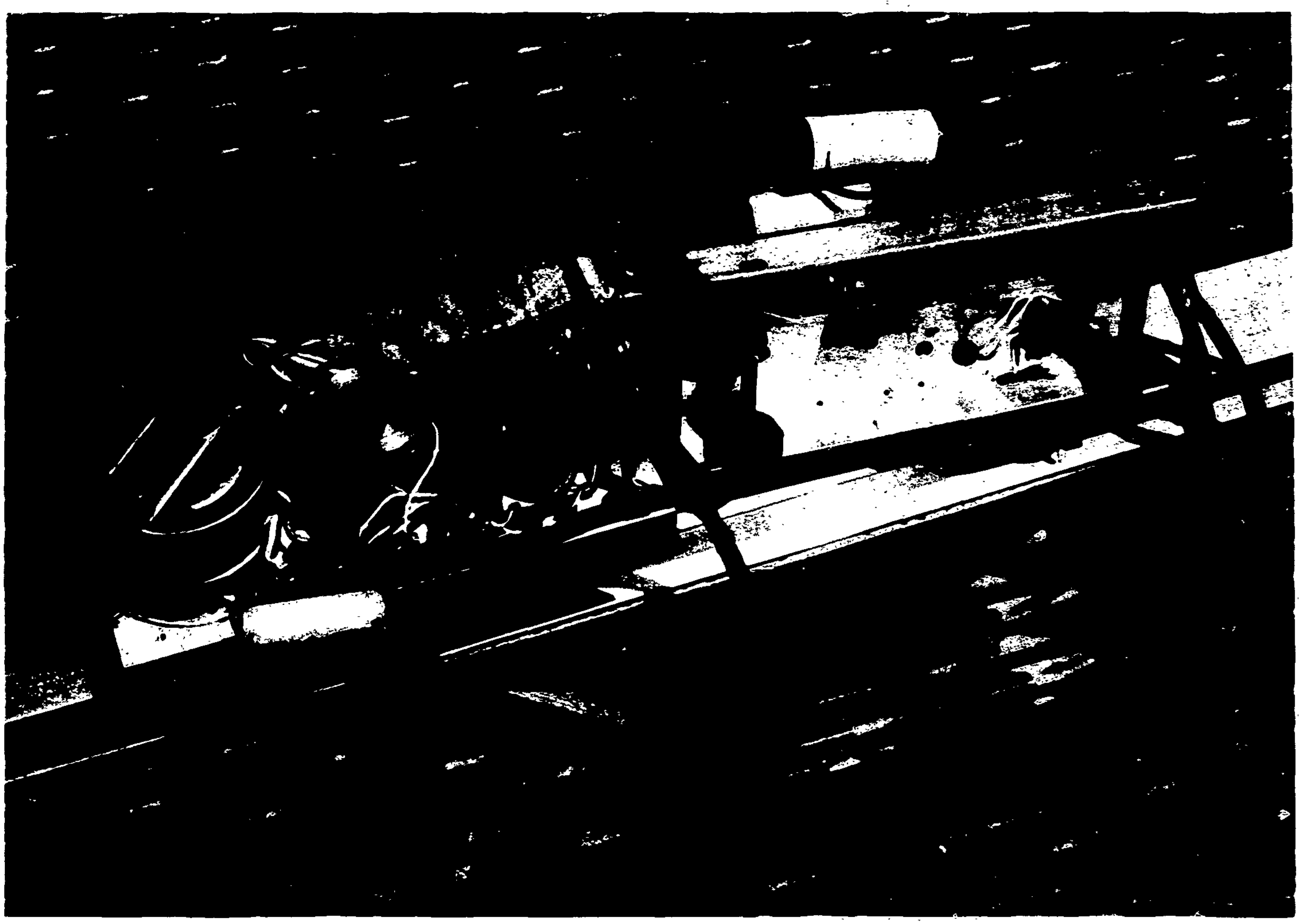

Figure 5. Photograph of two carriages on the aluminum rail enlarged to show components

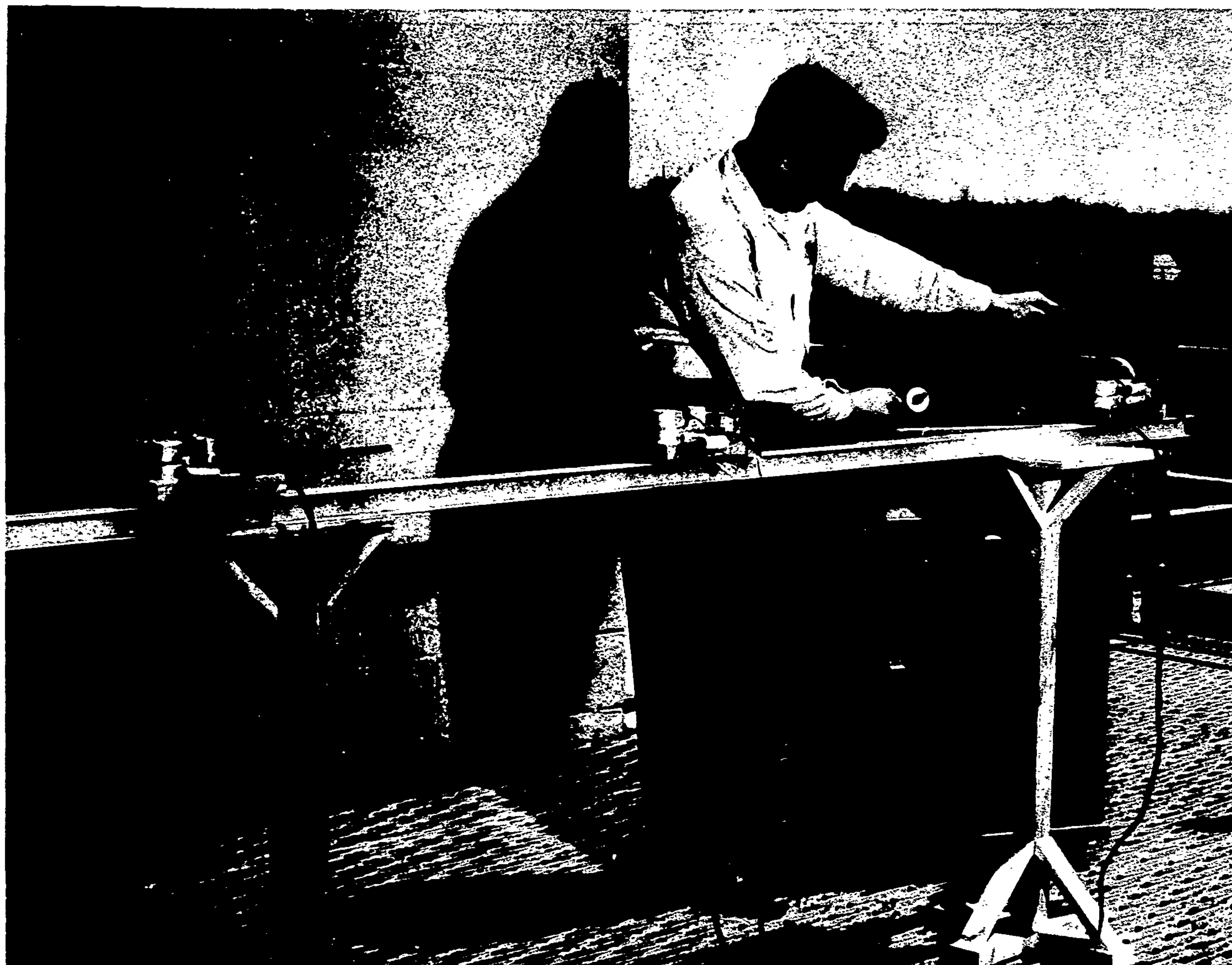

Figure 6. Photograph showing carriages on the rail

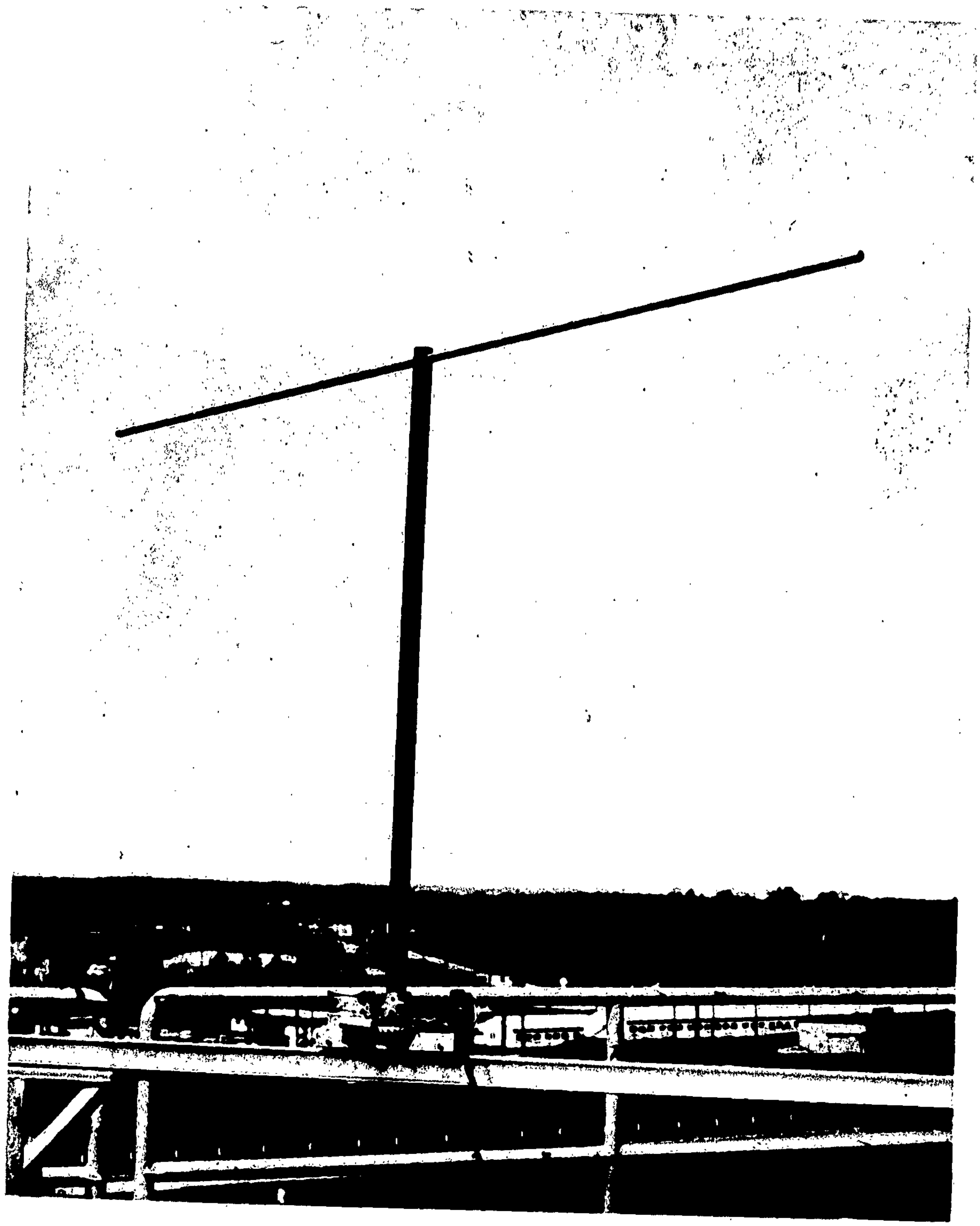

Figure 7. Photograph showing a dipole element mounted on a carriage

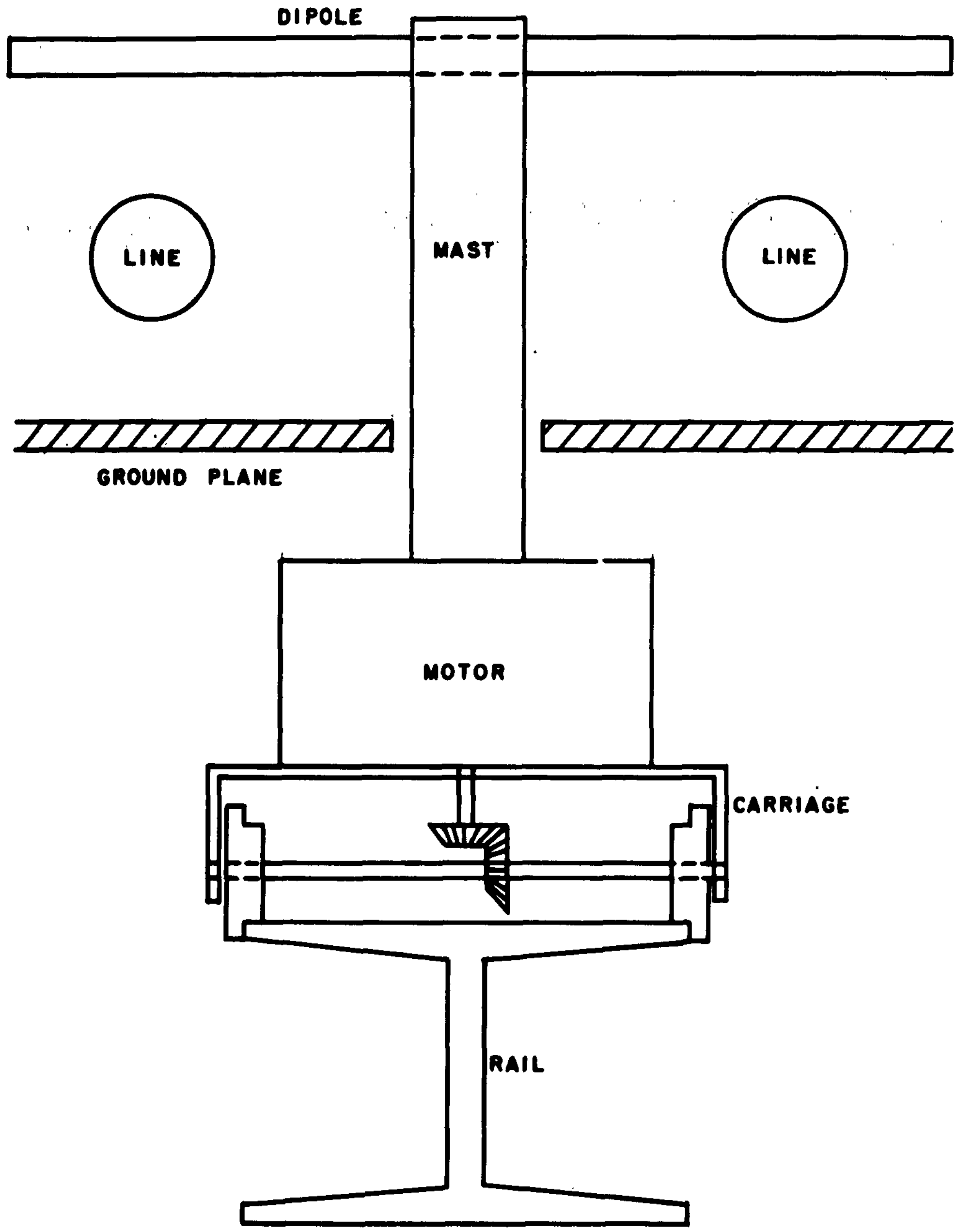

Figure 8. Mechanical arrangement

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2. Dipole antennas

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